Effects of Interference on Recognition of Tactile Pictures in Blindfolded Sighted

Participants

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the Faculty of Graduate Studies and Research
in Partial Fulfillment of the requirements for the degree**

Master of Arts

by

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Abstract

Recognition of raised-line pictures was tested in 36 Carleton University students to determine whether haptic representations are visual or multi-modal. Participants explored target raised-line pictures and were asked to recognize the target from three alternatives. Eight trials were completed in visual, lexical and tactile recognition modalities in control trials followed by trials with a concurrent interference task at exploration. For interference, participants were assigned to either an articulatory suppression (repeat “the” at a constant rate) or a visual interference (watch a visual display) condition, to prevent recoding into a verbal or visual code. Accuracy was higher at control compared to interference and for tactile compared to lexical recognition. Additionally, lexical recognition decreased with articulatory suppression whereas tactile recognition decreased with visual interference. Results suggest that raised-line pictures may be represented by coordinating visual and verbal codes and that a higher-order tactual memory store may not be necessary for haptic recognition.

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Introduction

Pictures are encountered on a daily basis and convey a variety of information, such as road signs warning of a curve ahead. Given the importance of pictures in quickly conveying information, raised-line drawings that can be felt by hand have been applied to research and education with blind individuals. It is therefore vital to understand how individuals are able to recognize representational two-dimensional input, in both visual and tactile formats. In the current study, participants tactually explored raised-line pictures, with or without concurrent visual and verbal interference tasks to determine the format in which raised-line pictures are represented in memory.

Before discussing how raised-line pictures may be recognized, a general overview of what is known about picture recognition is in order. Pictures tend to be instantly recognizable (Kennedy, 1974), an ability that requires little instruction or exposure. Infants restricted in viewing pictures and members of isolated communities are able to identify key components of outline pictures (Hochberg & Brooks, 1962; Hudson, 1960). What enables such easy recognition of pictures, even in conditions where exposure is limited?

How Pictures Are Perceived

There are several theories concerning how pictures are perceived as representations of objects in the world. One view of picture recognition is that similarities in features shared between the picture and the object facilitate identification, such that when features of a picture closely match those of the object, recognition is immediate (Bernheimer, 1961). Another similar view arguing for the importance of similarities between a picture and the depicted object suggests that when the surface of a picture

conveys similar information as the light array coming from the object, identification is facilitated (Gibson, 1971; Kennedy, 1974). For both theories, recognition of abstract depictions requires learning social codes and conventions (Bernheimer, 1961; Gibson, 1966). It has also been suggested that pictures do not necessarily have to convey similar light arrays but can instead convey similar optic arrays, which consist of the information in light (Gibson, 1966).

Finally, the symbol theory of pictorial information suggests that pictures do not necessarily share features with the objects they represent, but can instead use a set of conventions that standardize the way depictions can be interpreted in order to provide an analogue of the object (Arnheim, 1974; Steinberg, 1953). In this view, one would see a picture and name it based on associations that have been learned through the cultural context, similar to the way in which letters are used as symbols to convey information through language (Gibson, 1966; Gombrich, 1960).

All theories of picture perception propose that in recognizing a picture, key features are either compared to features of the object for similarities, or compared to a learned set of conventions. However, the theories differ in the type of information that must be compared. Theories that propose that similar light arrays between objects and their depictions facilitate recognition imply a reliance on vision, whereas theories that propose that pictures can be recognized based on learned conventions imply cognitive processes in addition to vision. This is important when considering the recognition of raised-line pictures, especially in individuals without vision.

Haptic Picture Perception

Congenitally blind individuals are able to recognize pictures presented tactually as accurately as sighted individuals despite never seeing a three-dimensional object, or its two-dimensional pictorial counterpart (Heller, 1989a), suggesting that picture recognition may not be based only on visual processes. Research using raised-line pictures is relatively new, but is useful in determining how pictures are recognized. Haptics is defined as active touch and haptic pictures are drawings that are felt by hand, either by raised-lines of a fraction of a millimetre or by bas-relief style embossments.

Identification of raised-line pictures has proved to be more difficult than identification of visual pictures, or haptic identification of objects. Early research on haptics generally showed a benefit of vision over touch in two-dimensional form discrimination tasks (Bryant & Raz, 1975; Cashdan, 1968). However, poor recognition of raised-line stimuli may occur because salient cues are not provided. Recognition of three-dimensional objects is over 95% accurate, indicating that haptics is indeed an efficient system when salient cues are available (Klatzky, Lederman, & Metzger, 1985). Also, haptics can be useful for the perception of form, especially when familiar with raised-line figures (Heller, Wilson, Steffen, Yoneyama, & Brackett, 2003).

The current study concentrates on the recognition of raised-line pictures in sighted individuals in order to determine how tactile information is represented in haptic working memory. Before continuing in depth with the known storage processes of haptic input in memory, it is first important to consider the processes involved in attempting to identify or recognize a raised-line picture. First, a search strategy must be employed to extract features of the picture, followed by a storage process where the extracted features must

be kept in memory in order for the picture to be compared with mental representations of objects, leading to identification.

Haptic Search Strategies

Haptics has often been considered a lesser perceptual sense than vision, as early work showed that when simultaneous tactile and visual input conflicted, participants responded according to the visual input (Rock & Victor, 1964). The difficulty in haptic recognition may be accounted for in terms of search strategies: haptic features are extracted from a drawing one after another, whereas visual features are extracted simultaneously through quick saccades of the eye. There may not necessarily be a perceptual deficit of touch *per se*, but rather, the relatively inefficient exploration process involved in haptics may cause difficulty in recognizing raised-line drawings compared to visual drawings (Lederman, Klatzky, Chataway, & Summers, 1990; Wijntjes, van Lienen, Verstijnen, & Kappers, 2008a).

Input from tactile pictures can be obtained through guided or unguided search strategies (sometimes referred to as passive and active exploration, respectively). In unguided exploration, participants are free to explore the picture as they wish, such that hand and digit use is not restricted and exploration may not necessarily continue in a systematic fashion. In guided exploration, the experimenter guides the participant, usually so that a single (index) finger of the dominant hand extracts features in a consistent and systematic manner (Magee & Kennedy, 1980; Symmons & Richardson, 2000).

Guided exploration of haptic stimuli improves performance compared to unguided exploration, because planning exploration may draw from limited resources in

the haptic system, or from limited attention or memory resources (Magee & Kennedy, 1980; Richardson, Wuillemin & MacKintosh, 1981). Using guided exploration as a search strategy in experimentation with raised-line pictures can therefore minimize performance deficits.

As haptics is defined as “active touch” several components can contribute to the recognition of haptic pictures. The “active” component is related to movement of the hand and arm, whereas there is also a purely tactile component related to the indentation of skin on the finger when a raised-line is felt. When components of haptic information are isolated, conditions involving movement tend to be more accurate than conditions without movement (Magee & Kennedy, 1980; Symmons, Richardson, & Wuillemin, 2008), suggesting that movement may be a more salient cue than touch itself. Movement cues are especially salient when determining distances within a haptic spatial layout, compared to when determining position where spatial referent cues are more salient (Lederman, Klatzky, & Barber, 1985).

Information from movements involved in haptics is acquired based on reference frameworks. Individuals with vision tend to code spatial cues relative to one another, whereas visually impaired and blind individuals tend to code the position of the hand relative to body position (Millar, 1981). In addition, reference to the overall arrangement of cues can improve performance in blind and visually impaired individuals (Ungar, Blades, & Spencer, 1995).

In summary, haptics may often be considered a lesser perceptual system than vision because of limited cues and longer exploration times. Furthermore, haptic working memory may have limited resources. Therefore, there may not be an inherent deficit in

haptics compared to vision, but considering differences in optimal search strategies for each process may equalize performance. For example, considering movements in haptic search, rather than tactile input alone, may improve performance. After information is efficiently extracted from raised-line pictures, the input must be stored in short-term memory.

Storage of Raised-line Pictures

When considering the storage of haptic information, it is important to understand the components of haptic memory. Currently, it appears that there is a short-term modality specific tactile store and a less specific longer-term component. The short term memory for tactile input is a sensory trace akin to iconic memory. It can hold up to 4 items and decays with time, up to .8 seconds (Bliss, 1966).

When participants are presented with a tactile sequence on their fingers, the last few stimuli in the sequence are better remembered than stimuli in the middle of the sequence. However, when participants receive an irrelevant tactile stimulus after presentation of the sequence, they do not show a recency effect for the last few stimuli in the sequence (Watkins & Watkins, 1974). The irrelevant stimulus may have therefore filled tactile memory. In another study, forgetting curves for the recall of the location of a tactile stimulus on the underside of the arm suggest that a sensory after-image may aid recall until 10 seconds have elapsed (Gilson & Baddeley, 1969), providing further support for a short-term tactile store, however, the information may have been coded spatially or verbally (Gallace & Spence, 2009).

Further evidence for a specific short-term and a less specific longer-term memory store comes from findings where recall of tactile sequences presented to the fingers was

disrupted by proactive interference at short inter-trial intervals, but not longer intervals. Furthermore, a visual task during the retention interval interfered most with recall compared to articulatory suppression or rest conditions, suggesting that tactile retention for longer intervals may share processes with vision (Sullivan & Turvey, 1974).

The involvement of a non-specific central memory resource has also been shown, as articulatory suppression, but not tactile interference, reduced performance on tactile recall tasks (Mahrer & Miles, 2002; Miles and Borthwick, 1996). Also, accuracy in discriminating between two vibro-tactile stimuli decreases when working memory load is high, suggesting that working memory is involved in attention to tactile information (Dalton, Lavie, & Spence, 2008).

Finally, in completing a haptic discrimination task, the stored representation must be compared to information in long-term memory. When sighted participants explore a tactile drawing and are then asked to choose from among three spoken words, they make a correct choice more often than when asked to choose from among three tactile drawings (Pathak & Pring, 1989), suggesting that haptic information can easily transfer to semantic memory components. However, blind participants performed better when choosing from the three tactile alternatives (Pathak & Pring, 1989), suggesting that without vision, tactile memory may be more efficient.

It therefore seems that once tactile information is acquired, there is a tactile sensory store that lasts from .8 to 10 seconds and a more central longer-term memory resource. However, the format of representation in the central memory resource remains ambiguous, though it is likely not purely tactile but is instead a multi-sensory verbal or spatial representation (Gallace & Spence, 2009). The working memory model has been

implicated to be involved in haptic memory, and will be explained as a model of short-term memory for haptic input that exceeds the length of the tactile store.

The Working Memory Model for Haptics

The working memory model is a widely accepted modal system generally consisting of a central executive, episodic buffer, and two slave systems: the visuo-spatial sketchpad and the phonological loop (Baddeley, 1986, 2000). The phonological loop processes language information and decays with time unless maintained by subvocal rehearsal, whereas the visuo-spatial sketchpad is responsible for storing and manipulating images but is poor at maintenance of temporal sequences. The episodic buffer is controlled by the central executive and integrates information from a variety of sources by interacting with long-term memory and creating a multi-dimensional code (Baddeley, 2000).

Early research on the visuo-spatial sketchpad showed that visuo-spatial tasks were disrupted by concurrent spatial tasks, but not by visual tasks, suggesting a dissociation between visual and spatial components of the visuo-spatial sketchpad (Baddeley, 1986). Although other research suggested that visual and spatial processing are not functionally distinct (Beech, 1984), two components of the visuo-spatial sketchpad have generally been assumed (Logie, 1995).

Aside from the distinction between visual and spatial components within the visuo-spatial sketchpad, a distinction has also been proposed between “active” and “passive” spatial components (Vecchi, Monticellai, & Cornoldi, 1995). The active component is responsible for the manipulation or reorganization of information, whereas the passive component is responsible for the maintenance of visuo-spatial information

(Eardley & Pring, 2007). Evidence for this dissociation comes from studies where the generation and transformation of mental images was impaired by a secondary task but maintenance was not, suggesting it is more passive (Bruyer & Scailquin, 1998).

Sighted participants perform better than congenitally blind participants in active spatial memory tasks, but not passive tasks, suggesting that vision is necessary for the active component of visuo-spatial processing, but maintenance is possible without visual experience (Vecchi et al., 1995). Furthermore, in two- and three- dimensional versions of an active spatial task where participants were asked to imagine a form out of a set of shapes that had been explored by hand, blind participants made fewer forms in two-dimensions than sighted participants (Eardley & Pring, 2007), providing further support that active spatial processing may rely on vision. Another paradigm compared the performance of late blind and sighted participants on an active spatial task, where two- or three- dimensional tactile matrices had to be remembered either alone, as pairs, or integrated into a single matrix. Late blind participants had an overall impairment in performance (Cattaneo, Vecchi, Monegato, Pece, & Cornoldi, 2007).

Together the studies provide support that active spatial tactile tasks may rely on vision, however, another study using two-dimensional matrices showed that congenitally visually impaired participants had similar performance compared to sighted controls but early congenitally monocular participants were less accurate (Vecchi et al., 2006), suggesting that impairments on active tasks may be related to the lack of exposure to simultaneous processing and not a lack of vision.

Although visuo-spatial working memory is able to store information from a variety of modalities, that blind individuals perform worse on active visuo-spatial tasks

compared to sighted individuals suggests that vision may be dominant in visuo-spatial processing (Vecchi, 1998) and that the visuo-spatial working memory system is set-up according to the sensory input that is received when it is being developed (Cattaneo et al., 2007). Spatial input may therefore be stored in the visuo-spatial sketchpad primarily by visual representations when vision is present as the system is being developed, but alternate representations may be dominant when vision is not present during set-up.

The dominance of vision is supported, as when early blind, late blind and sighted participants are asked to imagine target squares within a larger tactile matrix, there are no differences between groups; however, sighted and late blind participants use a visual strategy while early blind participants use a coordinate *XY* strategy (Vanlierde & Wanet-Defalque, 2004).

Research using the working memory model for haptics supports a view that haptic spatial information may be processed in the visuo-spatial sketchpad, which distinguishes between active and passive and visual and spatial processes. Performance on active spatial tactile tasks is impaired in individuals without vision, suggesting that even tactile tasks may rely on visual processes. However, alternate storage strategies may be involved when vision is absent during set-up of the visuo-spatial system. Raised-line pictures may therefore be represented in memory as visual images when vision is present during set-up of the visuo-spatial sketchpad, however, may have alternate types of representation when vision is not present.

Cross-modal Representations in Memory

If raised-line pictures are represented as visual images in the visuo-spatial sketchpad, then it is important to understand whether these images can be translated to

other modalities, such as a spatial or verbal description. On the other hand, if raised-line pictures are represented in memory in a less-specific format, it can be assumed that transfer between modalities is relatively easy. Therefore, determining the transfer of information across modalities can help determine how haptic input is represented in memory.

When participants are presented with a series of matrices in which target cells have to be remembered, performance does not differ between presentations in which the matrices were presented in a single modality versus presentations in which the matrices were presented in alternate modalities at exploration and test (Cattaneo & Vecchi, 2008). This suggests that representations generated by either visual or tactile spatial input are not specific to the modality in which the information was extracted, but that instead the input is translated into a representation that can be accessed by both vision and haptics.

Contrary to the finding that there were no differences between cross-modal and uni-modal recognition of target cells of a matrix, in another study, when participants were asked to explore a scene that consisted of seven objects and then identify the two objects that were in a new position, fewer errors were made when the scene was presented in the same modality at exploration and testing (Newell, Woods, Mernaugh, & Bulthoff, 2005). This suggests that visual and haptic input may be represented in different modalities, such that when testing is in the other modality, translation of the initial representation to the new modality results in errors. When participants were asked to repeat “the” while exploring the scene in order to prevent verbal coding, recognition in the haptic-haptic condition (but not in the visual-visual condition) was impaired, suggesting that haptic

stimuli may be encoded with verbal descriptions more so than visual stimuli (Newell et al., 2005).

When children haptically explored familiar and unfamiliar objects and had to identify target objects presented either visually or haptically, familiar objects were identified more often than unfamiliar objects in only the haptic-visual condition. When the objects were unfamiliar, responses were more often correct in the haptic-haptic condition compared to the haptic-visual condition (Bushnell & Baxt, 1999). This suggests that familiar objects elicit representations in several modalities based on previous explorations, whereas unfamiliar objects may only be represented in the modality in which they were explored and thus show poorer recognition across modalities.

Performance across modalities seems to provide unclear results as to whether information is stored in one modality and translated to other modalities depending on the task, or whether information is stored as a network of representations in several modalities. Representational format of haptic information may depend on task complexity (Cornoldi & Vecchi, 2000), visual experience (Vanlierde & Wanet-Defalque, 2004), and familiarity (Bushnell and Baxt, 1999).

Because the question of the current study is whether haptic information is stored as a visual image or a less specific representation, representational format depending on visual experience is of particular interest. If haptic memory depends on visual representations, individuals with little visual experience should show deficits in haptic memory. A preliminary model of haptic picture recognition was developed in order to provide a framework explaining differences in representation of haptic stimuli depending on visual experience.

The Partial Overlap Model

The partial overlap model posits that pictures are not represented as visual images, or as amodal spatial representations, but rather that there is a partial overlap between representations generated from the haptic and visual systems depending on level of visual experience. In the partial overlap model, selected features of a raised-line picture are extracted through a sequential exploration process and may then be integrated in a *haptic buffer*. The haptic buffer shares its limited resources between storage and operational components (see Figure 1).

The load on the haptic buffer can be reduced as participants learn to organize features into units. Remaining resources may then be allocated to the operational process, which feeds back to the original drawing and selects more detail, or more relevant features, therefore improving picture recognition. Once features are integrated into a recognizable form, pictures are more likely to be identified.

In addition, there is a partial overlap in visual and haptic processes that depends on visual experience. During feature extraction, sighted individuals may automatically convert haptic input into a visual mental image, congenitally blind individuals may be required to integrate the extracted features into a tactually recognizable form, and low vision individuals may use a combination of haptic memory and visual imagery when processing pictures.

Figure 1. The partial overlap model. Features of raised-line drawings are integrated in a haptic buffer that shares resources between operational and storage components.

There is neural evidence for an overlap in visual and haptic representations, as multi- and bi-modal cells exist in the parietal cortex that fire to inputs from more than one modality, therefore capable of providing convergence of haptic and visual input (Millar, 1994). That there are multi-modal association areas that integrate different sensory inputs, suggests that spatial representations do not occur in only one modality, but are multi-modal. Although the effect of blindness on convergence of input from different modalities is not yet known, there is possible reorganization depending on time of sensory deprivation (Millar, 1994). This plasticity following blindness provides support that there may be differences in representation of haptic stimuli depending on visual experience.

There is also behavioural evidence for a partial overlap between vision and haptics depending on visual experience. In a spatial task requiring children to trace a path that had previously been explored, congenitally blind children performed better when they had to trace the pathway in the opposite direction from how it was learned, whereas sighted children performed better when they had to trace the pathway in the

same direction as was learned (Millar, 1975). This suggests that blind and sighted children relied on different representational strategies, where the blind children used sequential haptic representations, and the sighted children relied on visual representations.

The partial overlap model draws from research on visuo-spatial working memory, as the storage component of the model is analogous to the passive component, and the operational component is analogous to the active component of the visuo-spatial sketchpad. However, it is unknown whether representation in the visuo-spatial sketchpad can be tactile as opposed to visual, or whether all representations are mostly spatial in format. The current study attempted to disentangle the representational formats stored in visuo-spatial working memory, to provide a first step in supporting the partial overlap model. Before elaborating on the study, a review of the current arguments for representation of haptic information in a visual format versus other less specific formats is necessary.

Visual Theory of Haptic Picture Perception

Piaget and Inhelder (1956) proposed that tactile perceptions and movements in children were translated into visual images as a means of support in developing representations of space. They further suggested that children learn to translate kinaesthetic codes into visual images late in the second year. Other early theories of cross-modal perception suggested that information from all modalities is integrated through visual reference codes (Warren & Pick, 1970), and that visual imagery is required to accurately identify haptic shapes (Cairns & Coll, 1977). A more recent and

less simplistic account of translation of haptic to visual representation is the *image-mediation model* (Lederman et al., 1990).

The image-mediation model of haptic picture processing posits that two-dimensional haptic input is translated into a visual image when cues are limited (Lederman et al., 1990). When cues are more abundant, such as when exploring three-dimensional objects, a *direct apprehension model* of haptic processing may be used, where haptics is considered a separate perceptual system from visual processes (Klatzky, Lederman, & Reed, 1987).

The image-mediation model was initially supported, as participants identified raised-line drawings faster when drawings were rated as easy to form a mental images of, and participants who rated high in the ability to generate vivid images rated the drawings as easier to image. This suggests a mediating role for visual imagery in haptic picture perception. Furthermore, congenitally blind participants were less accurate than sighted participants in recognizing raised-line drawings of common objects, a result which was interpreted to mean that the blind participants could not rely on visual image mediation (Lederman et al., 1990).

The image-mediation model of haptic recognition has been further supported by a variety of studies using different methodologies. When participants sketch the raised-line drawing that they just explored, identification is facilitated when the sketch provides visual feedback but not when the sketch provides haptic feedback (Wijntjes, van Lienen, Verstijnen, & Kappers, 2008a). This has been interpreted as support for a visual translation theory, as visual externalization of a raised-line drawing facilitated identification. As further support for such a theory, transcranial magnetic stimulation

applied over the occipital cortex interferes with performance on a spatial orientation task and participants report using visual imagery in the task. This suggests that visual processing may be involved in certain aspects of haptic discrimination (Zangaladze, Epstein, Grafton, & Sathian, 1999).

Also, when asked to complete a haptic task of setting a series of bars so that they are parallel, sighted and late blind participants show an improvement with a delay between bar setting, whereas early blind participants do not show an improvement with delay. Early blind participants also perform more variably than the sighted and late blind participants, suggesting that improvements due to delay may be related to translation of the haptic input into a primarily visual representation (Postma, Zuidhoek, Noordzij, & Kappers, 2008).

When congenitally blind and sighted participants were asked to judge whether two stimuli were the same or different in a tactile mental rotation task, all participants showed increased reaction time with increased angular disparity (Marmor & Zaback, 1976), a pattern that has been attributed to visual imagery in visual mental rotation tasks (Shepard & Metzler, 1971). However, congenitally blind participants took longer to discriminate between the shapes compared to sighted participants (Marmor & Zaback, 1976). Along with longer reaction times, congenitally blind participants also have higher error rates and slower mental rotation times (Millar, 1976; Roder, Rosler, & Hennighausen, 1997), suggesting that non-visual strategies can be used for mental rotation tasks, although they may not be as effective as visual imagery strategies (Kaski, 2002; Prather & Sathian, 2002).

Some support for a visual theory of haptic recognition has come from studies assuming that blind individuals do not have visual imagery, and comparing their performance with the performance of sighted individuals in order to uncover the role of visual imagery in haptic memory. However, in order for the studies to support a role for visual imagery in haptics, it must be proved that congenitally blind individuals do not have visual imagery. It is helpful to consider several studies concerned with whether congenitally blind individuals use visual imagery in tasks other than haptic perception. If lack of vision impairs visual imagery in more general tasks, then it is unlikely that congenitally blind individuals use visual imagery in perceiving raised-line pictures.

Use of Imagery in Congenitally Blind Individuals

An early review of studies on imagery in congenitally blind individuals showed that differences in performance between blind and sighted participants occurred mostly on tasks involving complex spatial relationships, and that performance for sighted participants was likely facilitated by visualization (Warren, 1977).

Congenitally blind individuals have shown difficulty in remembering multiple nouns (ranked by imageability), which may indicate that lack of vision impairs the use of visual imagery processes. However, impairments may also be due to the sequential nature of tactile and auditory processing, such that congenitally blind individuals may not have practice holding information simultaneously in memory (DeBeni & Cornoldi, 1988).

However, further evidence for impairment in visual imagery in blind individuals comes from a study where blind and sighted participants were asked to complete three imagery tasks. When asked to imagine objects, blind participants imagined objects to be within an arm's length, whereas sighted participants imagined objects as farther away.

Furthermore, sighted, but not blind participants reported “overflow” in imagining objects too close. Finally, when asked to point to the ends of an object at varying distances from the participant, sighted participants pointed at smaller angles with increasing distance, according to rules of perspective, but the blind participants did not (Arditi, Holtzman, & Kosslyn, 1988). Together, these results indicate that images generated by the blind participants may be mediated tactually.

However, another study has shown that blind children and adults show convergence when pointing to corners of a previously explored room, and that blind adults show convergence when pointing to objects within reaching space on a horizontal and vertical plane (Kennedy & Campbell, 1985). This suggests either that blind individuals may have some visual imagery or that another type of imagery can compensate for visual imagery in blind individuals, in order to accurately imagine perspective.

In a reasoning task where congenitally blind and sighted individuals had to evaluate a series of syllogisms which represented visual, visuo-spatial, or control relations, congenitally blind participants had equal performance across all types of relations whereas there was a decrement in performance for the sighted participants when the syllogisms concerned visual relations (Knauff & May, 2006). That congenitally blind individuals did not show an impedance effect due to the elicitation of visual imagery, suggests that their imagery may be spatial rather than visual. In another study using a variety of spatial tasks, congenitally blind participants showed similar patterns of results as sighted participants, however, they were slower in forming spatial images (Kerr,

1983), which further suggests that although visual imagery may be most efficient, it can be compensated for by spatial imagery processes.

That imagery in blind individuals may be spatial was again supported when late blind, congenitally blind, and sighted participants were compared on visual, auditory and spatial imagery tasks. Significant differences between blind and sighted participants were found in the visual and spatial imagery tasks (Noordzij, Zuidhoek, & Postma, 2007), suggesting the use of alternate strategies when vision is unavailable.

Imagery processes may therefore not be only visual, but may instead have visual and spatial components (Farah, Hammond, Levine, & Calviano, 1988) or may be multi-sensory representations of spatial, textural, or figural features of objects (DeBeni & Cornoldi, 1988). In summary, research with blind individuals has shown visual imagery may be impaired when vision is absent, but that alternate spatial imagery strategies are available for the successful completion of a variety of tasks. Some deficits in haptic processing may therefore occur due to impairments in visual imagery. However, because a variety of haptic tasks can be completed by congenitally blind individuals, haptic recognition may not rely on visual imagery processes alone but may be compensated for by spatial imagery.

Evidence against a Visual Theory of Haptic Picture Recognition

Equal performance between blind and sighted participants on a variety of tasks suggests that haptics is not mediated solely by visual imagery. In a texture discrimination task, there are no differences between congenitally blind, late blind and sighted individuals (Heller, 1989c). Congenitally blind and sighted children asked to draw the length of a previously drawn line misestimate the line's length when asked to imagine a

movement of a different length, suggesting that mental practice effects do not rely exclusively on visuo-spatial imagery (Millar & Ittyerah, 1992).

Furthermore, visual imagery alone does not facilitate the recognition of Braille characters in sighted participants (Heller, 1989b) and high imagery abilities in children are not correlated with performance on cross-modal tasks, though high spatial abilities were correlated with performance (Stoltz-Loike & Bornstein, 1987), suggesting that cross-modal tasks may rely on spatial representations rather than visual imagery.

The Neural Substrates of Haptic Recognition

Neuroimaging studies show an overlap in cortical activation during visual and haptic tasks (Grefkes, Weiss, Zilles, & Fink, 2002; Hadjikhani & Roland, 1998; James et al., 2002; Ricciardi et al., 2006; Saito, Okada, Morita, Yonekura, & Sadato, 2003) and MRI scans have also shown activation of the primary visual cortex during tactile processing of raised dot patterns (Merabet et al., 2007), suggesting that haptic exploration may activate a corresponding visual representation. That the occipital cortex is involved in visual imagery and is activated during tactile tasks seems to support a role of visual imagery in tactile discrimination (Kosslyn, Behrmann, & Jeannerod, 1995). However, activation of the occipital cortex can be accompanied by deactivation of the extrastriate cortex (Kosslyn et al., 1995), the opposite of what would be expected if imagery were involved.

Instead, activation of the occipital cortex may indicate its involvement in the integration of cross-modal sensory inputs (Merabet et al., 2007) or the generation of common haptic and visual representations (James et al., 2002), supporting a multi-modal view of tactile processing. Activation of the occipital cortex may also be related to

attention processes, as during a tactile discrimination task blind participants show a slow negative shift over the occipital cortex that varies with processing effort (Roder, Rosler, Hennighausen, & Nacker, 1996).

Further evidence that tactile tasks do not necessarily involve visual imagery comes from several studies suggesting that stimuli are processed in the sensory area in which they were perceived. In a mental rotation task using visual stimuli, maximum negativity was found over the occipital cortex, whereas in the same task using tactile stimuli, maximum negativity was found over the central cortex (Roder et al., 1997).

Furthermore, in a form matching task between tactile and visual stimuli in uni- and cross-modal conditions, PET analysis did not show an area activated in all conditions, but found that the right insula claustrum was activated in the cross-modal condition (Hadjikhani & Roland, 1998). Another study showed similar fronto-parietal networks activated with tactile-spatial and visuo-spatial matching tasks, suggesting that modality specific input may be translated into higher order representations (Ricciardi et al., 2006).

Representations of stimuli may therefore be formed in the sensory area in which the stimuli were perceived, with integration of representations from different sensory areas occurring in less specific regions, such as the insula claustrum or the intraparietal sulcus (Grefkes et al., 2002; Saito et al., 2003). Late positive potentials are evoked for cross-modal but not uni-modal conditions in a tactile and visual delayed matching task (Ohara, Lenz, & Zhou, 2006), suggesting that these components may be related to the transfer of information from one modality to another.

Neuroimaging during haptic tasks seems to support a multi-modal representation of haptic information because activation of the occipital cortex may reflect integration or attentional processes rather than visual imagery. Furthermore, haptic stimuli may be processed in the modality specific area in which they were perceived and then integrated into a higher order mental representation. Two theories of higher-order representations of haptic stimuli will be discussed next.

Less Specific Theories of Haptic Picture Perception

Amodal Theories

Spatial representations generated by vision and haptics may be quite similar (Cattaneo & Vecchi, 2008; Heller 2002). The amodal theory suggests that representations of haptic stimuli may be based on features that can be accessed across modalities (Walker-Andrews, 1994). Two-month old infants show visual recognition of previously felt shapes and may rely on contour (Streri & Molina, 1994), suggesting that shape representation may be based on invariant features that can be accessed across modalities.

Furthermore, recognition patterns for Braille and visual letters are similar when spatial resolution of the stimuli are equalized (Loomis, 1982) and presentation of haptic stimuli can prime recognition of similar visual stimuli and vice versa (Ballesteros, Gonzalez, Mayas, Garcia-Rodriguez, & Reales, 2009; Easton, Srinivas, & Greene, 1997; Reales & Ballesteros, 1999), suggesting similar representations for stimuli generated across modalities.

Cornoldi and Vecchi (2000) have developed a modification of visuo-spatial working memory where highly active tasks are less modality specific in their representation than passive tasks, which are more specific to the modality in which they

were perceived (Cattaneo, Fastame, Vecchi, & Cornoldi, 2006; Cornoldi & Vecchi, 2000). Although never completely amodal, the model suggests that spatial representations lose specificity the more complex a task becomes.

Multimodal Theories

One multimodal theory of representation suggests that when an object is seen in one modality, a representation is generated based on the perception of the object, but also based on prior experiences with the object (Bushnell, 1986). Evidence for multimodal representation of objects in infants shows that six-month olds look at familiar toys for a longer time when presented in visual and tactile formats simultaneously, but do not look at unfamiliar toys any longer when presented visually and tactually versus visually only (Bushnell, 1986), suggesting that they have formed a representation based on experience.

However, a congenitally blind child was able to identify a raised-line drawing even when it did not match his internal representation of the object (based on discussion with the experimenter; D'Angiulli, 2007). Thus, it seems that haptic picture identification does not rely only on beliefs about what an object should look like, but that there may be some principles of the perception of objects that are similar in vision and haptics (D'Angiulli, 2007; Kennedy & Bai, 2002).

Another well known multi-modal theory of representation is the dual-code theory, which suggests a representation system for the processing of non-verbal stimuli, and another for the processing of verbal stimuli. Children asked to imagine a three-dimensional shape felt by hand and children asked to name the shape showed no accuracy differences in visually recognizing a line drawing of the shape (Johnson, Paivio, & Clark,

1989), showing that objects are represented in either system and can be accessed to visually identify an object, and thus that the theory is multi-modal.

The partial overlap model, first explained on page 12, is a multi-modal model suggesting that haptic stimuli are processed by vision and haptics, resulting in representations in each modality. The dominance of each modality will depend on visual experience. Congenitally blind individuals may have a specific tactile representation; whereas sighted, visually impaired or late blind individuals may use a combination of haptics and vision, resulting in representations in each modality. All representations may also have a semantic component.

In the current study, interference techniques were used as a first test of the partial overlap model. Sighted participants were assigned to either an articulatory suppression or visual interference condition that interfered with specific components of haptic working memory. If haptic information is stored as a visual image, interference to the visuo-spatial sketchpad should have been more detrimental than if information is stored semantically. On the other hand, if retention of haptic information relies on verbal descriptions, performance should have been worse in the articulatory suppression condition. However, if haptic information can be stored in a variety of representations, or amodally, both groups should have had similar performance.

Interference Techniques

Research into determining whether haptic information is represented in memory as a visual image versus a less specific representation has been indirect, using techniques such as correlating visual image vividness with test performance on cross-modal tasks (Cairns & Coll, 1977), or varying instructions (Johnson et al., 1989). A more complete

investigation into haptic representations would involve interfering with specific aspects of working memory.

One of the first studies on mental representation showed that recall of information is disrupted the most when there is concurrent interference within the same modality (Brooks, 1968), suggesting the existence of separate representational formats. In a more recent study using interference techniques, participants were asked to look at or haptically explore a set of familiar and unfamiliar objects under four interference conditions (Lacey & Campbell, 2006).

Participants were placed into: (a) a visual interference condition where they watched a visuo-spatial display, (b) a verbal interference condition where they listened to an irrelevant commentary, (c) a haptic interference task where they continually manipulated a distracter object in the non-dominant hand, or (d) a control condition. These tasks were completed either during exploration of the objects, or during retrieval.

When interference was concurrent with object exploration, visual and verbal interference conditions interfered with unfamiliar object recognition more than tactile or control conditions. However, there were no differences between interference conditions for familiar object recognition (Lacey & Campbell, 2006). Representations for unfamiliar objects may therefore be mainly visual, but generated through a verbal description strategy. For familiar objects, a stable set of representations in verbal, haptic, and visual modalities was suggested (Lacey & Campbell, 2006).

When the same interference tasks were completed during the retrieval phase, there was no main effect of interference, or interference by familiarity interaction (Lacey &

Campbell, 2006), suggesting that objects are mentally represented in several different modalities.

Another study used spatial and non-spatial interference techniques to determine the format of haptic and visual representations (Sebastien, Mayas, Manso, & Ballesteros, 2008). A visual or haptic matrix was displayed and the participants were asked to remember the location of targets. The participants then completed one of four interference conditions over a six-second interval.

Participants were assigned to: (a) a haptic-spatial task where they continuously explored a wooden maze with the non-dominant hand, (b) a visuo-spatial task where they followed a moving dot on a computer screen, (c) an articulatory suppression task where they repeated the syllable “la”, or (d) a control task where they looked at a fixation point on the computer screen. Following interference, the participants had to mark the target locations on a blank matrix.

Spatial interference conditions impaired performance compared to control and articulatory suppression conditions (Sebastien et al., 2008), suggesting a shared spatial component in haptic working memory. However, the spatial interference effect was larger when the primary and secondary tasks were performed in the same modality, suggesting that within visuo-spatial working memory there are modality specific components (Sebastien et al., 2008).

As opposed to Lacey & Campbell (2006) who found that haptic objects are either stored as a set of representations in several modalities, or as a visual representation mediated by verbal descriptors, the results of Sebastien et al. (2008) suggest that haptic information may be represented in a less specific spatial format. In the present study,

similar interference techniques were used in order to disambiguate how haptic information is represented in memory.

Aim of the Study

An important difference between previous interference studies of haptic recognition and the current study is that two-dimensional raised-line drawings were used rather than objects. Representations of raised-line pictures may differ from object representations in that they may share fewer amodal properties between vision and touch. According to Lederman et al. (1990), haptic picture recognition may be mediated by visual imagery more than object recognition. However, recognition in congenitally blind individuals remains above chance (Heller, 1989a), suggesting an alternative to visual imagery may sometimes be used when imagery strategies are unavailable.

Furthermore, the raised-line drawings were of familiar objects, which was an important research tool in determining representational format in haptic memory. Because the raised-line drawings should have activated semantic representations of the depicted objects from memory, but might not necessarily have involved access of structural representations, the role of experience on mental representation of object properties could be elucidated.

Interference techniques were therefore used in the current study in order to determine the format of haptic mental representations in working memory. Furthermore, the ease of transfer of haptic information from different components was determined by testing recall in various modalities. The study was a first step in testing the partial overlap model which predicted that in sighted individuals, pictures will be encoded as multi-modal representations based on touch and vision.

Method

Participants

Thirty-six Carleton University undergraduate students (23 females, 13 males) were recruited for participation in the study through SONA, the online research participation system. Mean age of participants was 21.1 years, and two participants were left-handed with the rest being dominantly right-handed. Participation was completely voluntary and participants were aware that they were free to withdraw from the study at anytime if they ever felt uncomfortable. Participants were compensated with an increase of 2 percent towards their introductory psychology course grade.

Design

A 2x2x3 mixed-subjects design was used. The between-subjects factor was interference condition, where 18 participants were randomly assigned to each the visual interference and articulatory suppression conditions. The within-subjects factors were trial type (control vs. interference trials) and recognition type. For recognition type, the three alternatives were presented in a tactile, visual, and lexical format. Each participant completed 8 trials in each of the three recognition modalities, first for control trials and then for interference trials. Table 1 presents a summary table of the design.

Table 1

Summary table of the 2x2x3 mixed ANOVA design

Trial Type	Interference Type	Participant	Recognition Type		
			Tactile 1-8	Visual 1-8	Lexical 1-8
Control	Articulatory Suppression	1			
		...			
		18			
	Visual	19			
		...			
Interference	Articulatory Suppression	36			
		1			
		...			
	Visual	18			
		1			
		...			
		36			
		...			
		36			
		...			

*Materials and Apparatus**Object Sets*

Sixteen sets of three drawings were created (see Appendix), with one drawing in each set representing a target familiar object, another drawing representing a featural distracter, and the third drawing representing a random distracter. The featural distracter was a drawing of a familiar object that shared common perceptual features with the target drawing, whereas the random distracter did not share any salient perceptual features with the target drawing (Pathak & Pring, 1989). The sixteen sets of drawings were divided into two groups. Half the participants were randomly given group “A” of 8 object sets for all control trials, and group “B” of 8 pictures sets for all interference trials, and vice versa for the other half of participants. Figure 2 shows an example of an object set.

Figure 2. Practice set of drawings, adapted from Snodgrass and Vanderwart (1980). The apple is the target object, the ball is a distracter that shares similar perceptual features with the target (circular shape), and the drum is a random distracter, with no shared perceptual features. Each set of drawings was presented in a visual and tactile form, as well as lexically as words (i.e. apple, ball, and drum).

Out of the 16 sets, 12 were created using object triads described in Pathak and Pring (1989), and were drawn from pictures adapted from Kennedy and Bai (2002) and Snodgrass and Vanderwart (1980). The drawings were simplified to a few basic features in order to facilitate perception of the line drawings. Some object sets described in Pathak and Pring were adapted if they did not reflect salient similar or random features compared to the target drawing using the drawings derived from Snodgrass and Vanderwart, or if a drawing of an object could not be found within Snodgrass and Vanderwart, or Kennedy and Bai picture sets.

An additional four sets of drawings were adapted from pictures from Kennedy and Bai (2002) and Snodgrass and Vanderwart (1980), in order to generate 16 sets of drawing. These drawing sets were not described in Pathak and Pring (1989), but were created to have a target drawing, a similar featural distracter, and a random distracter. Within each set, the three objects were equivalently semantically related, but there was a distinct perceptual feature shared between the similar and target object.

Each set of three drawings was created in a tactile, visual, and lexical format. Drawings of each object were printed such that the long axis of the object spanned four inches. The drawings were then traced to create tactile and visual versions. Tactile object sets were made by applying pressure with a stylus to a Mylar sheet that was placed on top of a foam sheet, to create a raised line of a fraction of a millimetre, which could be felt on the same side as the pressure was applied. Visual object sets were created by tracing with a fine tipped black marker (that created lines of approximately the same thickness as the raised-lines) on to unlined white paper.

Finally, lexical formats of each drawing set were created by printing the common name of each object. For the pictures derived from Snodgrass and Vanderwart (1980), the most common name given to a presented object was used. Most pictures used had a name agreement of greater than 80 percent, with the exception of plane (60%), wrench (76%), moon (62%) and baseball bat (52%). Each stimulus was then glued onto a piece of hard poster board, approximately sized 5.5 x 7 inches. This created 48 stimuli in each format, as there were three objects in each of the sixteen sets.

Visual Interference

A Dynamic Visual Noise (McConnell & Quinn, 2004) display was presented on a computer monitor to participants in the visual interference condition (Figure 3). Standard specifications of the “Dots” program were used. The dynamic visual noise display consisted of an equal ratio of black and white dots with a size of 4x4 screen pixels each, contained in an area of 80 x 80 dots positioned in the centre of a black background. There was a change rate of 291 dots per second.

Figure 3. Sample screenshot from the Dynamic Visual Noise display (McConnell & Quinn, 2004). The black and white dots changed at a rate of 291 dots per second, creating a constantly changing visuo-spatial display.

Blindfolds

Raised-line pictures were hidden from participants by a raised shelf with a piece of cloth covering the front, with the computer monitor placed on top. In the control and articulatory suppression conditions, participants were additionally blindfolded by wearing ski goggles with the lenses blacked out with poster board. In the visual interference condition, participants were peripherally blindfolded by wearing ski goggles with the lenses blacked out with poster board, except in the center where holes were cut out to allow central vision.

A stopwatch was used to time exploration of target drawings, as well as to time the length of presentation of each distracter.

Procedure

Prior to beginning the study, participants read and signed a consent form, explaining that they were free to withdraw from the study at anytime without consequence if they ever felt uncomfortable.

Practice

Participants were seated in front of a computer and the task was described to them. A target picture was then placed under the shelf, out of view, and the participants completed a practice trial. Participants were blindfolded and the experimenter guided their index finger twice around a practice target picture. Exploration began at the top of the picture (at the beginning of a feature) and continued in a clockwise fashion until the entire picture had been explored, for approximately 10-15 seconds. The finger was then lifted and a second round of exploration began from the same starting point.

Participants were then presented with the three alternatives (target, random or similar distracter) in one of the three recognition types and asked to say which (“first”, “second”, or “third”) was the same as the target they had just explored. In the visual and lexical recognition conditions, the alternatives were presented on top of the shelf, one after another in random order, for approximately 5 seconds. In the tactile recognition condition, the experimenter guided the participant’s index finger once around each alternative, one after another for approximately 10-15 seconds.

The interference task assigned to the participants was also explained to participants prior to testing. In the visual interference condition, participants were briefly shown the visual display and in the articulatory suppression condition, participants were instructed that in the interference trials they would have to repeat “the” at a constant pace while exploring the target picture. Testing continued once the participant conveyed that they understood the experimental procedure.

Testing

Control Trials

All participants began testing with control trials, in which there was no concurrent task. In the control trials, participants completed three blocks of trials: 8 trials for tactile recognition, 8 trials for visual recognition, and 8 trials for lexical recognition. Order of recognition type was randomized and predetermined.

Each trial consisted of the experimenter guiding the participant's index finger around the target tactile picture for approximately 10-15 seconds, with the command "first time around the target". The participant's index finger was then lifted and the participant was told that it was the "second time around the target" and their index finger was guided around the contour of the target tactile picture for another 10-15 seconds.

The participant was then presented the target picture again, the similar featural distracter and the random distracter one after another in random order. In the visual and lexical recognition types, participants lifted the blindfold for the presentation of the distracters, which lasted approximately 5 seconds per picture. In the tactile recognition condition, the participants remained blindfolded for the presentation of distracters, which lasted approximately 10-15 seconds (once around) for each picture. Participants were then asked whether the first, second or third picture was the same as the target they just explored. If the participant changed their mind regarding a response, the first response given was recorded.

Once all 8 trials were completed in the first recognition type, the same procedure was repeated for the remaining two recognition types. The same group of pictures was presented, in random order, in the three different recognition types. Once all 24 control

trials (8 trials in the three recognition types) were completed, participants were given the option of having a 5-10 minute break before continuing with the interference trials.

Interference Trials

The experimental procedure was the same in the interference trials as the control trials, with the addition of an interference task and using a new group of pictures. Participants were randomly assigned to either the visual interference or the articulatory suppression condition before the experiment began.

Participants in the visual interference condition were peripherally blindfolded and seated in front of a computer and asked to watch the screen as Dynamic Visual Noise (McConnell & Quinn, 2004) was displayed. The experimenter began the visual display immediately before guiding the participant's index finger around the target tactile picture. Once the target picture had been explored for the second time, the visual display was stopped and the participant was shown the three distracters, in random order, and asked which one was the same as the target picture they had explored. Once an answer was given, the visual display was started again and exploration of the next picture began. This procedure was repeated for all 8 trials, in each the visual, tactile, and lexical recognition conditions. Once again, order of recognition, order of the pictures, and order of the distracters was randomized and predetermined.

Participants in the articulatory suppression condition were seated in front of a computer and fully blindfolded. They were asked to repeat "the" at a constant pace (Miles & Borthwick, 1996), of approximately once per second. For each trial, the participant was instructed to begin repeating "the" at the command "start". The experimenter then began to guide the participant's index finger around the target tactile

picture, and after the second exploration the participant was told to stop vocalization and was shown the three distracters.

This procedure was repeated for all 8 trials, in each the visual, tactile, and lexical recognition conditions (as in the control trials, the blindfold was lifted in the visual and tactile recognition conditions). Once again, order of recognition, order of the pictures, and order of the distracters was randomized and predetermined.

Debriefing

After completion of the testing phase, participants were given a debriefing form that explained the purpose of the study and asked if they had any remaining questions. There was no anticipated risk or deception involved in the study and all data collected was kept anonymously in a locked room which only the experimenters could access.

Results

Mixed-model ANOVAs were conducted on the mean number of targets correctly chosen, on the mean number of similar versus random stimuli chosen, and as control tests for recognition and block order. The between-subjects factor for the analyses was interference type (Interference) which had two levels: during interference trials, participants were assigned either to the visual interference or to the articulatory suppression condition. The within-subjects factors were trial type (Trial) which had two levels (control vs. interference trials) and recognition type (Recognition Modality) which had three levels: participants were shown alternatives to which they had to match the target object in visual, tactual, and lexical recognition modalities.

Preliminary analyses showed that all data approximated a normal distribution or could be assumed to conform to the normality assumption. Greenhouse-Geiser

corrections were applied to the within-subjects factors. Post-hoc analyses were conducted, applying modified Bonferroni corrections (Simes, 1986), to maintain $\alpha = .05$ over each family of comparisons.

Mean Number Correct

A mixed model 2x2x3 ANOVA was conducted on the mean number of targets correctly chosen. Means and standard deviations of the number of targets correctly chosen are shown in Table 2.

There was a significant interaction between Recognition Modality, Trial and Interference, $F(2, 68) = 3.65, p = .039$, partial $\eta^2 = .097$. The two way interactions between Recognition Modality and Interference, Trial and Interference, and Recognition Modality and Trial were all non-significant.

There was a significant main effect of Recognition Modality, $F(2, 68) = 18.84, p < .001$, partial $\eta^2 = .356$. Post hoc t -tests showed that the mean number of targets correctly chosen in the lexical condition ($M = 5.69, SE = 0.22$) was significantly lower than the mean number of targets chosen in the tactile ($M = 6.86, SE = 0.14$), $t(33) = 5.05, p < .001$ and visual ($M = 6.54, SE = 0.12$), $t(33) = 4.13, p = .001$, recognition conditions. The difference between the mean number of targets chosen for visual versus tactile recognition was not significant.

There was also a significant main effect of Trial, $F(1, 34) = 14.17, p = .001$, partial $\eta^2 = .294$, with more targets correctly chosen at control ($M = 6.66, SE = 0.13$) than interference ($M = 6.07, SE = 0.16$) trials. The main effect of Interference was not significant.

Table 2

Means and standard deviations of the number of targets correctly chosen, either with concurrent articulatory suppression (AS) or visual interference (VI)

Trial Type	Recognition Type	Interference Type	Mean	Standard Deviation
Control	Tactile	AS	7.11	1.08
		VI	7.17	0.71
	Visual	AS	6.89	0.83
		VI	6.78	0.94
	Lexical	AS	6.17	1.70
		VI	5.83	1.58
Interference	Tactile	AS	6.72	0.90
		VI	6.44	1.20
	Visual	AS	6.28	1.23
		VI	6.22	1.44
	Lexical	AS	4.83	1.51
		VI	5.94	1.47

Post-hoc paired samples *t*-tests for each recognition type were conducted within the articulatory suppression and visual interference conditions in order to interpret the significant interaction between Trial, Recognition Modality, and Interference.

In the articulatory suppression condition, there was a significant difference in accuracy between control and interference trials in the lexical recognition condition, $t(17) = 3.23, p = .005$, where accuracy was lower in the interference trials. In the tactile and visual recognition conditions, there was no significant difference between the mean number of targets chosen at control versus interference. However, for the tactile recognition condition the difference was marginally significant, $t(17) = 2.12, p = .049$, with fewer targets chosen at interference. Figure 4 shows the means and standard deviations of the number of targets chosen at each recognition condition for the articulatory suppression condition.

In the visual interference condition, there was a significant difference in the mean number of targets chosen at control trials versus interference trials in the tactile recognition condition, $t(17) = 2.60, p = .019$, with fewer targets chosen at interference. There was no significant difference between control and interference trials in the lexical or visual recognition conditions. Figure 5 shows the pattern of responses at each recognition condition for the visual interference condition.

Figure 4. Mean number of pictures correctly chosen (out of 8 trials) from three alternatives after tactually exploring a target picture, either in a control condition, or with concurrent articulatory suppression (repeating 'the' at a constant pace) at three different recognition conditions. Errors bars represent one standard error from the mean.

Figure 5. Mean number of pictures correctly chosen (out of 8 trials) from three alternatives after tactually exploring a target picture, either in a control condition, or with concurrent visual interference (watching the Dynamic Visual Noise display) at three different recognition conditions. Errors bars represent one standard error from the mean.

Control Analysis on Mean Number of Targets Correct

Additional analyses were conducted in order to determine if there were any extraneous variables that may have influenced the results. Neither gender nor handedness had a significant effect on mean number of targets correctly chosen, however, recognition order and block did have significant effects.

Recognition Order

An analysis of recognition order showed that the order of tactile, visual, and lexical recognition trials at control and interference had an effect on the mean number of target pictures correctly chosen. For control trials, when recognition order was added to the 2x2x3 ANOVA as a between subjects variable, there was no main effect of the order of recognition trials, and no significant interaction with either Interference or Recognition Modality. The three way interaction between Recognition Modality, Interference, and recognition order was also non-significant.

For interference trials, there was no main effect of recognition order, no significant interaction between recognition order and Interference or three way interaction between recognition order, Interference and Recognition Modality. There was, however, a significant interaction between recognition order and Recognition Modality, $F(10, 48) = 2.94, p = .006$. Multiple comparisons indicated that lexical accuracy was better when tactile presentation was followed first by visual, and then by lexical presentation ($M = 6.67, SE = .53$) as compared to lexical presentation occurring first, tactile presentation occurring next, and then visual presentation ($M = 4.75, SE = .53$; $t(30) = 3.80, p = .010$). All other comparisons were non-significant.

Block Analysis

An ANOVA was conducted on the mean number of targets correctly chosen, with trial type and block as within-subject factors, in order to determine whether there were practice or fatigue effects. There were significant main effects of block, $F(2, 70) = 4.69$, $p = .012$, and Trial, $F(1, 35) = 13.68$, $p = .001$. The interaction between block and Trial was not significant.

Recognition accuracy was worse in interference trials ($M = 6.07$, $SE = 0.16$) compared to control trials ($M = 6.65$, $SE = 0.13$). Furthermore, post hoc comparisons indicate that recognition accuracy was better in block three ($M = 6.58$, $SE = 0.16$) than block one ($M = 6.01$, $SE = 0.19$), $t(35) = 2.87$, $p = .021$. Recognition accuracy in block two ($M = 6.49$, $SE = 0.15$) did not differ significantly compared to block one or three.

Error Analysis

A mixed model 2x2x3x2 ANOVA was conducted on the mean number of distracters (similar versus random) chosen. The analysis mainly concerned the variable of error type, in order to determine if similar distracters were chosen more often than random distracters, and therefore, only the effects including error type will be reported.

There was a significant main effect of error type, $F(1, 34) = 33.59$, $p < .001$, partial $\eta^2 = .50$, a significant interaction between error type and Recognition Modality, $F(2, 33) = 13.10$, $p < .001$, partial $\eta^2 = .33$, and a significant interaction between error type, Recognition Modality, and Trial, $F(2, 33) = 4.33$, $p = .021$, partial $\eta^2 = .03$. The remaining two, three, and four way interactions were not significant. Table 3 shows the means and standard deviations of the number of similar versus random objects chosen when an error was made.

Table 3

Means and standard deviations (SD) of the number of similar and random targets chosen, either with concurrent articulatory suppression (AS) or visual interference (VI)

Trial Type	Recognition Type	Interference Type	Error Type			
			Similar		Random	
			Mean	SD	Mean	SD
Control	Tactile	AS	0.56	0.92	0.33	0.49
		VI	0.61	0.61	0.22	0.43
	Visual	AS	0.89	0.76	0.22	0.43
		VI	0.94	0.80	0.28	0.58
	Lexical	AS	1.33	1.41	0.50	0.62
		VI	1.44	1.04	0.72	1.07
Interference	Tactile	AS	0.61	0.78	0.72	0.96
		VI	0.94	1.11	0.61	0.78
	Visual	AS	1.11	0.90	0.61	0.85
		VI	1.00	0.97	0.78	0.88
	Lexical	AS	2.39	1.15	0.83	1.15
		VI	1.78	1.31	0.28	0.58

The main effect of error was a result of similar distracters ($M = 1.13$, $SE = 0.09$) being chosen more often than random distracters ($M = 0.51$, $SE = 0.07$). In order to interpret the three way interaction between type of error made, Recognition Modality and Trial, repeated measures analyses were conducted within each trial type. For control trials, there was still a main effect of error type, with similar objects being chosen more often than random objects, $F(1, 34) = 21.45$, $p < .001$, however, the two-way interaction between Recognition Modality and error type was not significant.

For interference trials, there was a main effect of error type, again with similar stimuli being chosen more often than random stimuli, $F(1, 34) = 15.21$, $p < .001$. However, the interaction between Recognition Modality and type of error made was significant, $F(2, 68) = 15.04$, $p < .001$. Post hoc paired samples *t*-tests comparing the number of similar versus random stimuli chosen in each recognition condition for interference trials were conducted.

There was no significant difference between the number of similar and random distracters chosen in the tactile and visual recognition conditions. There was, however, a significant difference in the number of similar objects chosen compared to random objects in the lexical recognition condition, $t(35) = 6.10$, $p < .001$. Figure 6 shows the pattern of errors shown in control and interference (collapsed across visual interference and articulatory suppression) trials.

Figure 6. Mean number of similar versus random pictures incorrectly chosen from three alternatives after tactually exploring a target picture, either in a control condition or with a concurrent interference task, at three different recognition conditions.

Discussion

When participants matched a previously felt target to one of three alternatives, the number of targets correctly chosen at interference decreased compared to control trials. Additionally, interference type interacted with recognition modality and trial type, such that recognition accuracy decreased in control versus interference trials in the lexical recognition condition with articulatory suppression and in the tactile recognition condition with visual interference. Possible interpretations of the current pattern of results on the storage of haptic information will be considered, followed by a more detailed account of the interference effects for each recognition condition. Finally, implications on working memory and partial overlap models will be discussed.

Possible Models of Haptic Picture Recognition

The current study was conducted in order to determine whether haptic information is stored within working memory as a visual image, a spatial code, or a multi-modal code. It seems likely that haptic information may not be exclusively stored as a visual image, as visual interference did not consistently impair recognition accuracy. Specifically, participants were still able to recognize haptic information visually and lexically when visual interference limited their ability to visualize the haptic pictures. Additionally, it is unlikely that haptic information is specifically maintained in working memory by an abstract, spatial representation. If haptic information were represented spatially, performance would have been unaffected by both interference conditions in each recognition modality. It therefore seems reasonable to infer that haptic information may be represented using more than a single modality-specific code.

The specificity of interference effects on different recognition modalities has implications on how haptic pictures may be mentally represented. Two hypotheses will be described as possible explanations of the nature of representation of haptic information.

First, it is possible that the modality in which haptic information is stored depends on the modality in which the information must be retrieved. Specifically, input may be translated to the output modality in order to facilitate rehearsal (Millar, 1994). Therefore, haptic information would be stored as a visual representation when recognition is from visual alternatives, as a verbal representation when recognition is from lexical alternatives and in a tactile specific modality when recognition is from tactile alternatives.

Such a theory has previously been supported in cross-modal tasks between kinesthetics and vision, where the kinesthetic-visual condition showed error patterns similar to those characteristic for visual memory and the visual-kinesthetic condition showed error patterns similar to kinesthetic representation (Jones & Connolly, 1970). This therefore suggests that when the recognition modality is known, inputs are translated to the modality of the recognition task.

However, when visual imagery abilities are correlated to cross-modal task performance, high visual imagers make fewer errors than low visual imagers, suggesting that representations may be translated to a visual image regardless of the modality of recognition (Cairns & Coll, 1977). Furthermore, within-modal recognition is better than cross-modal recognition (Newell et al., 2005), suggesting that translation of the input modality to the recognition modality is not always beneficial.

If tactile information were represented in the format of the recognition task, articulatory suppression would be predicted to interfere with lexical recognition. Since articulatory suppression did indeed impair performance in the lexical recognition condition, it is possible that the input could not be translated to the verbal code necessary for recognizing a word. On the other hand, if tactile information were translated to the modality of recognition, visual interference should have impaired performance in the visual recognition task, which it did not. Additionally, visual interference impaired performance in the tactile recognition condition, a pattern that was not predicted if tactile information were translated to the modality of recognition.

Since the theory that haptic information is translated to the modality of the recognition task is not strongly supported by the present results, or by previous research, an alternative explanation may be necessary. One such explanation of the selectivity of interference across recognition conditions is that representations of tactile information in memory may be multi-modal in nature, and thus represented in at least a visual and verbal code. For recognition to occur, representations elicited by the alternatives at recognition should match at least one stored representation of the target drawing.

Task analysis for cross-modal tasks suggests that recognition depends on encoding information, internally representing it, and then on deciding between the similarity of the representation and a new alternative (Stoltz-Loike & Bornstein, 1987). In most studies, an implicit assumption is that in deciding how similar two stimuli are, mental representations must be compared (e.g. Bushnell & Baxt, 1999; Lacey & Campbell, 2006). It therefore seems plausible that in exploring a tactile stimulus, representations are generated in visual and verbal codes and matched to each alternative.

This theory could explain the present pattern of results in each recognition modality as follows.

Recognition from Tactile Alternatives

Visual interference lowered the number of correct targets chosen compared to control trials in the tactile recognition condition and articulatory suppression also marginally interfered with tactile recognition accuracy. Interference with the formation of visual images and verbal descriptions may therefore subtly impair the ability to retain input from tactile pictures for subsequent tactile recognition, suggesting the generation of a verbal code and a visual image at exploration. Since stimuli presented at recognition were tactile, the alternatives again elicited verbal and visual images. Thus, even when interference blocked one modality of representation at exploration, the remaining representation was able to be matched with a representation of the alternatives. Therefore, recognition rates remained quite high even in interference trials (82%).

Accuracy may have slightly decreased from control to interference trials because of the additive effects of dual codes. Verbal and visual codes are independent and therefore, when information is represented in each format, memory performance improves (Paivio, 1975). In control trials, a visual image and a verbal description may have been formed, and each code may have had an additive effect on memory. During interference trials, the loss of one code may have resulted in a decrement in memory performance, regardless of which code remained. The remaining representation may have been sufficient, though not optimal, to match to representations of the alternative for recognition.

Recognition from Visual Alternatives

Neither articulatory suppression nor visual interference conditions impaired accuracy among visual alternatives, suggesting that verbal descriptions and visual images may both be effective strategies in remembering tactile information for visual recognition tasks. This may have occurred because processes involved in comparing a perceptual representation to visual pictures may differ compared to the processes involved in comparing perceptual representations to lexical or tactile alternatives.

Two-dimensional visual pictures may be treated as familiar, due to experience in seeing objects and their representations, whereas tactile pictures may be treated as unfamiliar because of a lack of experience with objects represented as raised-lines. Recognition of familiar and unfamiliar objects may use different processes. Perceptual representations may be compared for unfamiliar object recognition, while perceptual representations may be compared to prototypes activated from long-term memory, as well as to perceptual representations for familiar object recognition (Bushnell & Baxt, 1999). Raised-line drawings may be treated as unfamiliar objects, making recognition from tactile alternatives more susceptible to interference, whereas visual pictures are likely to be treated as familiar objects which elicit a network of representations and are more robust against interference effects (Lacey & Campbell, 2006).

Therefore, in the current study, the target tactile pictures may have been represented as visual images and verbal codes at exploration. In control trials, these perceptual representations were likely to be compared to long-term and perceptual representations elicited by the visual pictures and matched. In interference trials, when one perceptual representation was not possible due to the secondary task, the remaining

representation may have been matched to a long-term representation elicited by the visual picture that was in the same modality in which the target was stored. Due to the network of representations elicited in various modalities, visual recognition may therefore be less susceptible to interference.

Recognition from Lexical Alternatives

Articulatory suppression decreased the number of targets correctly chosen from three different words but visual interference did not. Visual and verbal representations may therefore be generated at exploration, but must be matched to a name at recognition. In the articulatory suppression condition, a visual image may not be able to be matched to a name as accurately as a semantic description, so recognition accuracy decreased compared to control trials. In the visual interference condition, the names at recognition could be matched to the verbal description generated at exploration, therefore leaving recognition unimpaired.

Repetition of the syllable “the” therefore likely filled the limited resources of the phonological loop, therefore causing the tactile pictures to be unable to be stored as verbal descriptions. It is possible that participants in the articulatory suppression condition created a visual image of the tactile picture, a technique that was not as efficient as verbal descriptions that were available to participants who watched a concurrent visual display, as indicated by lower accuracy in the articulatory suppression compared to visual interference condition.

Tactile Accuracy Compared to Visual and Lexical Accuracy

Tactile recognition rates were the most accurate for matching a target to the correct alternative as compared to lexical and visual recognition rates. This is likely to

have occurred because recognition tends to be highest when initial presentation of the stimulus and testing are in the same modality, as different modalities may involve different encoding processes (Newell et al., 2005) and translation to another modality is error-prone (Mahrer & Miles, 2002).

It is somewhat surprising that accuracy in the tactile recognition condition was the highest of the recognition modalities, since the presentation of the three alternatives took twice as long as in the visual and lexical recognition conditions in order to account for the sequential nature of haptic encoding. The longer presentation times resulted in a longer retention interval. However, any errors caused by the longer retention interval were likely compensated for by the advantage of exploration and testing being within the same modality.

Lexical recognition rates were the worst of the three recognition conditions. The task of recognizing a target from three words may have been more difficult than a task of matching a target to a picture, since the target object had to be named. In fact, when categorical information is provided, identification rates of raised-line pictures increase, and recognition of a target word from three tactile alternatives, with or without categorical information, increases accuracy compared to an identification task (Heller, Calcaterra, Burson, & Tyler, 1996). This suggests that difficulty in accessing semantic memory may be responsible for low identification rates of raised-line drawings. Since the lexical recognition condition was similar to an identification task, in that the drawing had to be named in order to be recognized, the target picture may not have been accurately labelled, making a lexical match more difficult.

When alternatives were presented as pictures, features of the pictures could be directly compared to a mental representation of the target drawing. On the other hand, in the lexical recognition condition, a word presented as an alternative may have been represented in a visual image in various ways, depending on the mental prototype of the object. Therefore, when participants tried to match the features of the target with an object name, each object may have shared features with the target depending on the features represented in memory. Thus, the prototypes that participants imagined when presented with an object name may have shared more characteristics than the visual or tactile pictures that were shown, making recognition in the lexical condition more difficult.

In another study where participants were required to choose a previously explored tactile picture from three object names, performance in the lexical condition was better than performance in the tactile condition (Pathak & Pring, 1989). It was presumed that tactual representations were compared to long-term representations that included both verbal and sensory representations and that the formation of semantic hypotheses as to what the object was aided in recognition. Future studies are necessary to determine whether semantic information improves or impairs recognition, however, differences in object sets, or a difference between adults and children may explain the results.

In summary, a dual-coding theory, where at exploration visual images and verbal codes are generated, may explain the obtained pattern of results. The visual and verbal representations generated at exploration are likely to be matched to perceptual or long-term representations generated by the alternatives. A match occurs when the representation of the target is in the same modality as the representations of the

alternative. Interference is therefore most detrimental in the lexical condition, where long-term representations of the alternatives are more variable than in the tactile or visual recognition conditions.

Recognition Rates

Recognition Rates Compared to Other Studies

Recognition rates in the current study showed a different pattern than those found by Pathak and Pring (1989), the only other known study that tested tactile picture perception using recognition of a target from three alternatives. Control trials in the tactile recognition condition were identical to the task used by Pathak and Pring; however, they found recognition accuracy of 66% for sighted participants, whereas recognition accuracy in the present control trials was 89% and 82% in interference trials.

On the other hand, in the lexical recognition task, Pathak and Pring (1989) found that recognition rates increased to 76%, whereas in the current study recognition rates decreased to 75% as compared to the tactile recognition task. Accuracy in the lexical recognition condition is therefore rather consistent between studies; however, whether lexical recognition was easier or harder than tactile recognition depends on the tactile recognition rates.

Differences in tactile recognition rates between studies may be related to the exploration strategies used. Both studies guided exploration around the target and alternative drawings, however, in the present study participants were guided twice around the target drawing. A second exploration of the target may have accounted for better tactile recognition rates, possibly because additional features may have been stored or better verbal descriptions may have been developed.

Although larger pictures are recognized more easily than smaller pictures (Wijntjes, van Lienen, Verstijnen, & Kappers, 2008b), pictures used by Pathak and Pring (1989) were 4 x 3" and pictures used in the current study were approximately 4" at the axis of the longest feature. Since picture size between studies was similar, it is unlikely that increased accuracy in the current study was related to larger pictures.

Another possible reason that tactile recognition rates varied between studies is the choice of alternatives. Most object sets in the current study were the same as those used by Pathak and Pring (1989) however, the drawings chosen to represent a particular object may have differed across studies. If this were the case, drawings used in the present study may have had more salient differences between objects, resulting in higher recognition rates. Additionally, 4 object sets were created and some object sets were adapted for the current study. It is possible that objects within created sets were easier to differentiate between compared to the sets used by Pathak and Pring.

Finally, a possible explanation for differences in tactile recognition rates between Pathak and Pring's (1989) study and the current study is that their participants were children aged 12- 14 years old, whereas the current participants were adults aged 17- 45 years old. Adults may use more effective and purposeful exploratory procedures in exploring haptic stimuli than children (Minogue & Jones, 2006), therefore adults may have extracted more haptic information from the raised-line drawings compared to children, therefore improving recognition in the current study.

In a haptic object recognition task, Lacey and Campbell (2006) found that familiar object recognition was not impaired by interference tasks, whereas unfamiliar object recognition was impaired by both visual and articulatory suppression interference

at encoding. This is similar to the current findings within the tactile recognition modality, supporting a theory that tactile information may be represented through visual images and verbal descriptions.

Tactile recognition of raised-line pictures therefore seems to involve processes similar to those used for recognition of unfamiliar objects. This seems plausible, since raised-line pictures do not share all properties, such as size or texture, with the objects they represent (Klatzky et al., 1985). Experience with three-dimensional objects may not translate to their two-dimensional representations, therefore even though the raised-line drawings represent familiar objects, the drawings themselves may be perceived as unfamiliar. In fact, participants in Pathak and Pring (1989) were so poor at identification that they believed drawings they were exploring were random patterns. Because identification of raised-line drawings is difficult, raised-line pictures may be treated as unfamiliar.

However, another study using interference techniques did not support the current results. Sebastien et al. (2008) found that interference tasks that were spatial in nature impaired performance on a haptic-spatial task of remembering target squares within a matrix. In this case, haptic and visual interference tasks interfered with performance, but an articulatory suppression task did not, suggesting a spatial representation. On the other hand, accuracy was impaired by articulatory suppression in a tactile recall task (Miles & Borthwick, 1996). Due to task differences, it may be that different types of input are optimally represented in different modalities. Tasks less spatial in nature, such as tactile picture recognition tasks, may be more reliant on verbal coding than spatial tasks, which may be more reliant on imagery strategies.

Efficiency of the Haptic System

Given that in control trials accuracy in the tactile recognition condition was 89%, the highest of the three recognition conditions, it is evident that the haptic system may not necessarily be deficient compared to the visual system. Instead, haptics may be an effective perceptual system, especially when tasks and stimuli are appropriate to the haptic system. Raised-line pictures are often not identified as readily as three-dimensional objects, since object properties such as weight and texture are limited (Klatzky et al., 1985). However, the present study shows that recognition of two-dimensional pictures can be quite high.

Identification rates of tactile pictures in sighted participants are as low as 33% (Lederman et al., 1990) but Klatzky et al. (1985) found that most identification errors were the result of misnaming an object into a superordinate category, a categorically related category, or a categorical preordinate. When such a naming error was considered correct, identification rates increased to 96%. Furthermore, providing categorical information also increased identification rates (Heller et al., 1996). Current recognition rates may therefore have been high because naming was not required, so cues from raised-line drawings were enough to assign the target and alternatives to separate categories (though they may not have been enough to name to object). Low identification rates are therefore unlikely to be failures in encoding the features of a drawing but are rather naming failures.

It therefore seems that haptic information in raised-line pictures can be retained, especially when categorical information or alternatives are provided. Errors are therefore unlikely to be due to encoding failures related to a deficient haptic system, but may be

related to semantic failures. As such, an error analysis was conducted to determine if similar objects were indeed chosen more often than random objects, a pattern that would suggest that errors were related to confusing encoded features with similar features of the alternatives rather than global deficits of the haptic system.

When an error was made in choosing a target object from three alternatives, similar objects were chosen more often than random objects, suggesting that errors were the result of confusion between shared features of two objects. This supports a feature theory of haptic picture processing, where features of the target object were identified and then matched to features of the alternatives (Pathak & Pring, 1989).

However, similar objects were not always chosen more often than random objects, as there was an interaction between error, trial and recognition types. In control trials, similar objects were always chosen more often than random objects, but in interference trials, similar objects were chosen more often than random objects only in the lexical recognition condition. It therefore seems that for control trials, features of the target were matched to the alternatives but that interference sometimes affected the ability to match remembered features of the target to a word.

The lexical recognition condition may have been particularly prone to confusing a similar object with the target object, because the image of an alternative that was generated by the participant may contain features that are more similar to the target than the alternative shown in the visual condition. Conversely, in the tactile and visual recognition conditions, random and similar stimuli may have been chosen equally as often because an inadequate representation of the target may have been generated in interference trials, thus having minimal information to compare to the alternatives.

In summary, similar stimuli were generally chosen more often than random stimuli when an error was made, especially in control trials. This suggests that features of haptic pictures may be compared to features of the alternatives in a recognition task. It should, however, be noted that though visually the similar objects seemed to have more features in common with the target than the random object, when explored by hand it seemed as though some random objects had more movements in common with the target than the similar object. Similar and random alternatives therefore may not have accurately reflected haptic features shared between stimuli and some caution should be taken in interpreting the error analysis.

Implications for Haptic Memory Models

The Working Memory Model

Looking at the effects of the interference tasks, it may be possible to determine how haptic information is stored in working memory. Articulatory suppression interferes with subvocal rehearsal within the phonological loop (Baddeley, 1986; Salamé & Baddeley, 1982), therefore since recognition accuracy decreased in the lexical recognition condition when participants repeated “the”, haptic information appears to be at least partly stored within the phonological loop. Additionally, the visual nature of the Dynamic Visual Noise display interferes with the visuo-spatial sketchpad (Quinn & McConnell, 1996). Therefore, since recognition accuracy decreased in the tactile recognition condition, haptic information may also sometimes be stored as a visual image.

It is not surprising that verbal descriptions are important for lexical recognition since the target was named in order to correctly recognize it from alternative object

names. The role of the phonological loop in memory for haptic information that must be tactually recognized is somewhat more surprising. Since the phonological loop rehearses information of a verbal nature, even though semantic processes are not directly evident, it appears that haptic information may sometimes be translated into verbal descriptions. Since visual interference decreased tactile recognition accuracy, haptic information may also be sometimes translated into a visual image in the visuo-spatial sketchpad.

Finally, although neither articulatory suppression nor visual interference interfered with recognition from visual alternatives, the phonological loop and visuo-spatial sketchpad may not necessarily be uninvolved in storing haptic information for visual recognition. Instead, both sub-systems may be involved, making tactile information redundant and therefore less susceptible to interference.

It therefore appears that when a haptic picture is explored under control conditions in blindfolded sighted participants, a verbal description is rehearsed in the phonological loop and a visual image is generated in the visuo-spatial sketchpad. The episodic buffer integrates information across modalities (Baddeley, 2000), and therefore may integrate the visual and verbal representations in order to create a single code to compare to the alternatives.

For the tactile recognition task, the episodic buffer may integrate the visual and verbal representations encoded at exploration of the target and compare them to the representations generated by the alternatives. When there was interference, only one representation may have been generated and compared to the alternatives, resulting in more errors because of the lack of elaboration of the representations of the target.

For the visual recognition task, under control conditions, the episodic buffer may have again integrated representations stored in the phonological loop and the visuo-spatial sketchpad and compared them to the network of representations elicited by the visual pictures and their associated prior experiences. In interference conditions, since a network of representations may have been elicited, the modality of the remaining representation of the target will likely have matched the long-term representations elicited by the alternatives, thus resulting in minimal interference.

Finally, for the lexical recognition condition, in control conditions, both a verbal description and a visual image may have been formed. However, at recognition, only the verbal description would have matched the modality of each alternative. If articulatory suppression inhibited the formation of a verbal description, the visual image formed may not have matched the visual image elicited by the object name, resulting in decreased recognition accuracy. Since the visual interference condition does not inhibit the generation of a verbal description, recognition accuracy was unimpaired.

Haptic information therefore appears to be represented in working memory in the phonological loop and visuo-spatial sketchpad, thus creating a multi-modal code. As verbal and visual representations are posited, the dual-code approach to human cognition may be an accurate theory concerning haptic recognition.

The Dual-Code Approach

The dual-code approach to human cognition suggests that there are two main representational systems, a non-verbal and a verbal sub-system. The systems are used alone, or in combination and characteristics of the stimuli, task instructions, and individual preferences partly determine which sub-system is used to complete a task

(Johnson et al., 1989). Results support the dual-coding approach, as visual imagery (non-verbal) and verbal strategies were used to represent tactile information, likely as a combination of visual images and verbal descriptions of features of the picture. However, since interference tasks currently only tested visual and verbal representations, it is possible that tactile information can be mentally represented in additional formats, such as haptically or through a combination of strategies.

A cross-modal tactile to visual recognition task revealed that when children were given no instructions as to what type of strategy they should use for the task, most children applied a naming strategy (Johnson et al., 1989), suggesting that semantic representation may be used in cross-modal tasks more spontaneously than visual imagery. Additionally, when instructions were given to children to use either a naming or an imagery strategy, performance depended on measured visuo-spatial and referential abilities. In comparing results of the current study to those of Johnson et al., it is evident that individual differences in abilities can partly determine which strategies are used to mentally represent information.

Neural Substrates Involved in a Dual-Code Representation

Given that tactile information can be mentally represented as a visual image, activation of the occipital cortex during haptic tasks (James et al., 2002; Merabet et al., 2007) may correlate to the generation of the visual image and may not be the result of the attention processes (Roder et al., 1996). If activation of the occipital cortex correlates to the generation of visual images, the generation of verbal descriptions should similarly correlate to activation of language areas within the brain.

When a tactile pattern is presented to a participant's hand, cortical activation begins at the primary somatosensory cortex, then spreads to secondary somatosensory areas and parietal and frontal cortices, including Broca's Area (Reed, Hagler, Marinkovich, Dale & Halgren, 2009). A PET study also showed increased mean cerebral blood flow to Broca's area during a tactile discrimination task, indicating that the discrimination task generated internal language representations (Seitz, Roland, Bohm, Greitz & Stone-Elander, 1991). Tactile information therefore seems to initially be represented within the somatosensory cortex but then spreads to areas responsible for cross-modal integration, including areas that generate visual and verbal representations, providing a neural basis for verbal and visual representations of haptic information.

The Partial Overlap Model

An aim of the current study was to provide a first test of the partial overlap model (first described on page 13), a multi-modal model that supposed the use of haptic and visual processes in extracting haptic information from pictures. Haptic information was then said to be integrated in a haptic buffer, freeing resources to feedback to object exploration in order to select more features and eventually lead to identification of the drawing. Results indicate that the multi-modal hypothesis is accurate, although haptic information seems to be represented by, at least, visual and verbal codes and not necessarily a haptic representation. Subsequently, the hypothesized haptic buffer may not be necessary.

Data and Arguments against the Haptic Buffer

If haptic information were stored exclusively within a tactile memory store, it would not be susceptible to interference from other components of working memory

because information within buffers is independent from one another (Baddeley, 1986; Bruyer & Scailquin, 1998). The detrimental effects of visual interference and articulatory suppression on recognition accuracy therefore suggests that there may not be a short-term memory store specific to retaining tactile information, as information is, at least partly, stored in the phonological loop and visuo-spatial sketchpad. Verbal, visual and/or spatial representations may therefore be sufficient for storing haptic information in working memory, suggesting that tactile memory may not be as simple as visual or auditory memory, in that there is not necessarily a representation specific to tactile memory (Gallace & Spence, 2009).

As the current study did not have a tactile interference task, there was no direct test for a tactile-specific memory store. As already mentioned, haptic interference did not impair cross-modal object recognition (Lacey & Campbell, 2006), but did impair performance on a spatial matrix task (Sebastien et al., 2008). However, in a tactile recognition task consisting of remembering a sequence of stimuli presented on the hand, tactile interference (dragging a pen across the hand) did not effect recognition, whereas articulatory suppression (repeating the word “the”) lowered recognition (Mahrer & Miles, 2002). This substantiates that tactile information may be verbally recoded and that a tactile specific store for time intervals exceeding the limit of the sensory store is unlikely.

Additionally, the results support a main goal of the partial overlap model: to show that visual imagery is not the only process involved in the recognition of haptic information. If visual imagery alone mediated haptic picture perception, articulatory suppression should not have interfered with recognition accuracy, as it did in the lexical recognition condition. However, visual interference did impair recognition accuracy in

the tactile recognition condition, suggesting that visual and verbal strategies may both be used to retain haptic information within working memory.

A New Partial Overlap Model

Although there are aspects of the partial overlap model that remain untested, the model can be adapted based on the current results. In this new model, haptic information may be serially extracted through exploration of the drawing, generating verbal descriptions and visual images that are stored in the phonological loop and visuo-spatial sketchpad of working memory, respectively. By creating a visual image or verbal description, the serial features are integrated into chunks, thus freeing resources for feedback to select additional features or for additional organizational procedures. The visual and verbal representations are likely integrated within the episodic buffer and compared to long-term representations to identify the drawing. Figure 7 shows a representation of the new partial overlap model.

Congenitally totally blind individuals may be less accurate than sighted individuals in identifying haptic pictures, however, they are able to identify at least 10% of raised-line pictures (Lederman et al., 1990). Other studies show that congenitally blind individuals may be able to identify haptic drawings at a rate above chance (Heller, 1989a). If haptic information were represented in memory exclusively as a visual image, haptic picture recognition would not be possible for congenitally totally blind individuals. The representation of haptic information in memory as both a visual image and a verbal description helps to explain how congenitally totally blind individuals are able to recognize haptic pictures, as congenitally blind individuals may be capable of using effective verbal descriptions to recognize haptic pictures.

Figure 7. Adaptation to the partial overlap model. Features of raised-line pictures are explored sequentially and maintained as a verbal code and a visual image within the phonological loop and visuo-spatial sketchpad, respectively. Representations are integrated within the episodic buffer and matched to object representations in long-term memory (LTM) for identification. If identification cannot be made, resources freed from integration of the codes feedback to select additional features from the drawing.

Indeed, congenitally blind individuals have increased verbal memory, correlated with increased activation in the primary visual cortex, as compared to sighted individuals (Amedi, Raz, Painka, Malach, & Zohary, 2003). It is therefore possible that congenitally blind individuals may compensate for a lack of visual imagery by the use of more effective verbal descriptions. It is also possible that blind individuals develop alternate strategies to represent haptic information in order to compensate for poor visual imagery. For example, early blind individuals use a coordinate XY strategy to remember tactile matrices (Vanlierde & Wanet-Defalque, 2004).

It therefore appears that memory for haptic information is not specific to a particular modality. Sighted individuals seem to have multi-modal, visual and verbal representations; however, this may not extend to representations generated by visually impaired individuals. Further tests of the partial overlap model would help to determine the plasticity of representational strategies depending on visual experience.

Limitations and Future Research

There are several limitations to consider in the design and interpretation of the current study, that if addressed could lead to more conclusive evidence on the nature of haptic representations in memory.

Limitations of the Study

The visual interference task may not have been strong enough to interfere with the visuo-spatial sketchpad, therefore causing interference in only one recognition condition. However, standard Dynamic Visual Noise specifications were used, similar to those used by Lacey and Campbell (2006), McConnell and Quinn (2004) and Quinn and McConnell (1996), which have resulted in significant interference effects. It is also possible that participants did not fully adhere to instructions to watch the display, since compliance could not be monitored as easily as with the articulatory suppression task.

However, given that watching the Dynamic Visual Noise display impaired performance for tactile picture recognition, it is likely that participants paid attention to the task and that the Dynamic Visual Noise display was strong enough to interfere with the formation of visual images. Nonetheless, replication of the obtained pattern of results would provide more conclusive evidence for the role of the visuo-spatial sketchpad in recognition of haptic information.

Additionally, the interference tasks may have been a distraction, occupying resources in the central executive rather than interfering with specific components of working memory. However, if this were the case, impairment in accuracy in each of the recognition conditions would be expected, whereas the current results show that although all interference trials had lower accuracy than control trials, the difference was not always significant. The effects of the interference tasks were therefore selective, and likely not related to attention deficits.

Furthermore, the secondary tasks were chosen because they were passive tasks that did not require an additional action to be taken, therefore limiting demand on attention resources. In fact, Dynamic Visual Noise (Quinn & McConnell, 1996) has been found to have little effect on resources of the central executive, and articulatory suppression at a rate of 3-4 items per second has minimal attention demands (Baddeley, 1986). It is therefore more likely that interference effects were due mainly to blocking specific components of working memory, however, it is possible that limiting attention due to a secondary task had minor effects on recognition accuracy.

Another limitation of the study concerns the interpretation of the results, with interference effects being interpreted as deficits in the formation of visual mental images or verbal descriptions. However, the interference tasks may have impaired the ability to code movements while leaving the ability to form visual mental images or verbal descriptions of the features of the drawings unaffected. Converting movement to spatial representations is a heuristic used in judging distances when visual images cannot be immediately made, such as when exploration is serial, as with tactile picture recognition (Lederman et al., 1985).

The articulatory suppression task may therefore have interfered with the ability to verbally code movements involved in the exploration of tactile pictures. For example, participants may have been unable to form verbal descriptions such as “there is a line going down, then to the left, then back up and to the right”, in order to describe a square. Visual interference may have interfered with movement coding for a slightly different reason. The directions of the dots in the Dynamic Visual Noise display may have been confused with the direction of exploration of the tactile picture, therefore while watching the display and exploring the tactile picture, movements may not have been remembered as left vs. right, or up vs. down. Thus, both visual interference and articulatory suppression may have decreased the number of targets correctly chosen because of interference in the coding of movements, rather than interference to specifically visual or phonological components of working memory.

However, there were selective impairments related to visual versus verbal interference, therefore, even if the interference tasks disrupted encoding of movement rather than of features, the appropriate components of working memory were likely interfered with. Nonetheless, task manipulations affecting the encoding of movement input would be helpful to further elucidate the information important to haptic recognition. For example, participants could hold their index finger in a stationary position while a picture is moved underneath it during interference and control trials to determine the importance of movement versus cutaneous input in generating visual and verbal codes.

Another limitation is that similar and random object drawings may not have accurately reflected shared features. Thus, interpreting errors to mean that features of

haptic drawings were encoded but confused with similar features may be presumptuous. Pilot studies where participants rate haptic drawings on a scale of similarity would help to confirm that errors in encoding are related to shared features between objects.

Furthermore, recognition rates were quite high even when there were significant interference effects. Consequently, haptic picture recognition may involve processes that were not tested in our study since if haptic picture processing depended wholly on visual images and/or verbal descriptions, recognition in interference trials may have been much lower. Thus, it is unclear whether recognition rates were high at interference trials because haptic picture processing uses verbal and visual representations, such that interference to one modality does not completely interfere with haptic picture perception, or because the secondary tasks did not interfere with the main representations used in storing haptic information.

In future studies, the task could be made more difficult by guiding exploration once around the target, rather than twice, by unguided exploration of the stimuli, by having an identification rather than recognition task or by using different pictures for each recognition condition, possibly negating practice effects. Additionally, the difficulty and nature of the interference tasks could be manipulated. For example, interference tasks could be combined in order to see if visual imagery and verbal descriptions are the only strategies used in haptic picture perception, or if additional processes may also be important.

Another limitation concerning the design of the study is that interference always followed control trials, however, participants may have been bored or fatigued during the interference trials, therefore impairing their accuracy. The study was designed in this

manner because it was believed that recognition accuracy should improve with practice, however, practice with the task may not have generalized to the new set of pictures introduced in the interference trials.

An analysis of the mean number of targets chosen depending on blocks within each trial type showed a significant main effect of block, where accuracy for the third (last) block was better than for the first block. Therefore, performance did improve with practice with the task, irrelevant of trial type. Since the design of the study was biased against interference, due to practice related improvements with time, that there were impairments in performance shows that the secondary tasks were quite effective in interfering with working memory.

Future Task Manipulations

Haptic interference tasks, such as manipulating an object in the non-dominant hand or exploring a tactile maze concurrent to exploration of the tactile pictures would be helpful to determine if there are memory representations that retain specific tactile information, perhaps in a haptic buffer. It would be important to ensure that the task is passive, does not involve attention processes and that it is the same level of difficulty as other interference tasks.

Another manipulation of the task could be to present the recognition conditions in random order throughout the trials, making participants unaware of which recognition modality will be presented. This would help to determine if different strategies for haptic picture recognition can be chosen according to the modality of the recognition condition. For example, it is possible that participants knew they would have to match the target to a visual picture and therefore tried to visualize the drawing. Randomly presenting the

different recognition modalities would make strategies impossible to predict, thus determining the role participants have in generating mental representations of haptic information.

Also, since representation of haptic pictures seems to be similar to that for unfamiliar objects, it would be interesting to see how haptic pictures are represented in participants familiar with raised-line pictures. This could be done either by testing visually impaired individuals who are already familiar with raised line materials such as Braille, or by giving sighted participants experience with raised-line pictures. Familiarity could influence representations by creating a network of representations in different modalities, making them less susceptible to interference, such that recognition of familiar objects in the tactile modality would be similar to recognition from visual modalities.

Finally, as the current study was designed to be a first step in testing the partial overlap model, a logical next step would be to test participants of various visual abilities, in order to determine if there are differences in representation of haptic information depending on visual experience. The current study revealed that sighted individuals likely use a combination of visual imagery and verbal descriptions in order to remember haptic information. Future research could help determine if congenitally blind individuals have developed alternate strategies to compensate for poor visual imagery.

If articulatory suppression does not completely interfere with haptic picture recognition, congenitally blind individuals may have developed additional strategies for haptic picture perception. These could include the development of a coordinate strategy or increased tactile memory. Also, future studies with late blind and visually impaired

individuals would help to determine the importance and flexibility of visual versus verbal representations.

Conclusions

Visual and verbal interference tasks disrupt haptic picture recognition selectively depending on the modality of recognition, with articulatory suppression disrupting lexical recognition and visual interference disrupting tactile recognition. It is therefore likely that haptic information is stored in the phonological loop as a verbal description and in the visuo-spatial sketchpad as a visual image. These representations may then be integrated in the episodic buffer to be compared to long-term representations, or stimuli currently being perceived. Recognition likely occurs when a modality of representation of the target matches a modality of representation of the alternatives. Likewise, identification likely occurs when representation of haptic information matches in modality and content to representations elicited by semantic information in long-term memory.

A dual-code representation of haptic information has important fundamental and practical applications. First, a role for the slave systems in haptic working memory has been supported. A second important fundamental application is that haptic information is likely translated from the input modality to a new representation, suggesting that cross-modal tasks may involve translating input to a new modality. Furthermore, that haptic recognition is high when alternative information is provided suggests that haptics is not necessarily inferior to vision.

Practically, since haptic information can be represented in visual and verbal formats, blind individuals may not necessarily have a perceptual deficit in retaining haptic information. Therefore, knowledge that verbal descriptions can aid in storing

haptic information could be used such that teaching strategies, such as mnemonics, could be applied to help generate better verbal descriptions. In addition, since visual and verbal representations each have slightly different information (Paivio, 1975), graphic aids could be used in the education of sighted and visually impaired individuals to provide a more thorough understanding than using one modality alone. It is therefore evident that haptics can provide an elaborate understanding of the objects encountered by touch everyday.

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Appendix

Practice Set

Set 1

Set 2

Set 3

Set 4

Set 5

Set 6

Set 7

Set 8

Set 9

Set 10

Set 11

Set 12

Set 13

Set 14

Set 15

Set 16